FRODOSPEC Integral Fibre Unit

STATEMENT OF WORK

Laboratório Nacional de Astrofísica

FACTI
FRODOSPEC Integral Fibre Feed

STATEMENT OF WORK

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Acronym List

ATM  Acceptance Test Meeting
CDR  Critical Design Review
CoDR  Conceptual Design Review
CPM  Critical Path Method
EMV  Expected Monetary Value
FACTI  Fundação de Apoio à Capacitação em Tecnologia da Informação
FO  Fore-Optics
IFF  Integral Fibre Feed
IFU  Integral Fibre Unit
ISB  Instrument Selector Box
LNA  Laboratorio Nacional de Astrofísica
MCT  Ministry of Science and Technology
OPD  Observatório do Pico dos Dias
PERT  Program Evaluation and Review Technique
PI  Principal Investigator
SIFS  SOAR Integral Field Unit Spectrograph
SOAR  Southern Astrophysical Research Telescope
STELES  SOAR Telescope Echelle Spectrograph
UNIFEI  Universidade Federal de Itajubá / Federal University of Itajuba
USP  Universidade de São Paulo / University of São Paulo

Authors

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Vanessa B. Macanhan - Mechanical Engineering
Fernando G. Santoro - Mechanical Engineering
1. Overview

In this document we present the LNA / FACTI proposal for constructing the fibre fed Integral Field Unit (IFU) for the FRODOSPEC spectrograph, to be installed at the Liverpool telescope. The proposal follows the requirements presented in the TENDER REFERENCE No JMU 05/09 and its technical reference prepared by Dr. Sue Worswick.

The proposed IFU consists of 100 fibres fed through a 10x10 square array of 0.5mm microlenses. Each microlens covers 1arc sec, and the total field of view covers an area of 100 square arcseconds. The mapping of the input array follows a “z” pattern, designed to minimize fibre to fibre light contamination and provide a better mapping for data reduction.

In section 2 we describe the proposed Optical Layout, the optical components and the expected efficiency. We also discuss the mapping of the input array and the possibility of masking if required for data reduction. In section 3 we present the mechanical layout and the system components. In section 4 we present the management plan for building the IFU, the required budget, and the schedule for completion. In section 4 we also present the project team and a brief listing of its expertise.

LNA agrees to carry out this work in accordance with sound engineering and technical practice and to that standard of care, skill, and diligence normally provided by a professional organization in the performance of similar services.
2. Optical Layout

2.1. The lenslet array

The Liverpool telescope delivers an f/10 focal plane and the image scale is 97 microns per arcsecond. In the example proposed by Sue Worswick, a lenslet with a 200µm pitch is used. The assembly of the array with such a small pitch is not possible using the techniques we developed in our fibre labs. So in order to guarantee that the array of lenslet/fibres can be built, we are proposing a custom LIMO Lissotschenko Mikrooptik GmbH square lenslet with a 500µm pitch and F/5. Apart from being made of optical glass instead of being an epoxy replica, the whole system is factory assembled and coated, reducing the project risks. Although the AOA array is less expensive from shelf, the manpower and time required for assembling the components will make it as much expensive as the LIMO one.

<table>
<thead>
<tr>
<th>Specification Data</th>
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<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Average radius</td>
</tr>
<tr>
<td>Effective focal length EFL @ 633 nm</td>
</tr>
</tbody>
</table>

Each microlens has to cover 1 arcsec in the sky, and the total field of view cover an area of 100 square arcseconds. The mapping of the input array follows a “z” pattern, designed to minimize fiber to fiber light contamination and provide a better mapping for data reduction.

2.2. The Fore-Optics

A magnification of a factor of ~5.15 between the telescope focal plane and the lenslet array is required to cover a square input field of 10 x 10 arcseconds (using the LIMO lenslet described in the table above). An example using Melles Griot lenses (magnification 5) is shown in the following diagram.
This configuration will slightly underfill the 50mm fibre core giving almost no margin to accommodate chromatic and pupil aberrations and alignment tolerances. If a custom design is used for the fore-optics lenses to keep the magnification of 5.15, a more comfortable margin to accommodate aberrations and decentering errors is giving. If the spectrograph field is big enough to accommodate 144 fibres (12 x 12 array) the margin would be be even better and the efficiency higher.

The illumination pattern at the input end of the fibres is shown in the diagram below for a magnification factor of 5.

If the spectrograph can accommodate 144 fibers, a bigger margin to accommodate aberrations and fiber centering errors could be achieved for a magnification of ~6.25. An example of the illumination pattern at the input end of the fibres is shown in the diagram below for a magnification factor of 6.25 (using Melles Griot lenses).
In case the spectrograph can accommodate a 144 fibres slit, we would recommend using a magnification of ~6.25 to have a bigger margin to accommodate errors and keep efficiency high.

2.3. Optical Coating

In order to minimize reflection losses, we propose to use a broadband AR coating like the Spectrum Thin Films Astronomical Coating for all the air/glass interfaces. The figure below shows a typical AR reflectance curve for a Silica surface.

Transmittance curve of the intended coating for the fore-optics lenses and slit output.

2.4. Input array

We propose an Input array mapping following a Z pattern. This mapping allows an easy image reconstruction and an efficient flat field masking (as described in 2.7) needed to account for the fibre contamination.
2.5. Slit output

*Input array mapping following a Z pattern.*

*Schematic diagram of a slit block and microscope images of part of a slit block epoxy after polishing*
2.6. Expected efficiency

Adopting the standard Polymicro fibre output curve for a 10m length, the mean transmission value for the proposed coatings (99.5%, see 2.3) for the 8 glass/air surfaces and considering a typical focal degradation for the applied fibre assembly method developed at LNA (85%) the goal performance, on a best-effort basis, for the FRODOSPEC IFU is shown in the figure bellow. The losses due fibre decentering were not computed here since this value will depend on the adopted fore-optics design as described in 2.2.
2.7. Spectral Format and Data Reduction – Masking the fibre input

As the spectrograph output beam will exit straight from the fibres and will have no microlens assemblies, the spectra separation on the detector will be dictated by the fibre to fibre centre distance, independently of the spectrograph plate scale on the detector or the number of pixels covered by one spectrum.

With the fiber parameters required for FRODOSPEC an important overlapping of neighbor spectra will occur, as it also happens in Eucalyptus (LNA), SIFS (SOAR) and SPIRAL (AAO). The spectrum overlapping will be between 3 to 1 or 4 to 1. This means that if one single fibre spectra gaussian profile occupies 18 pixels (spatial direction) in the detector, 6 or 5 pixels of the gaussian will be detected above the confusion level and the wings will be bellow this level (see figure bellow). One single spectrum contaminates 2 neighbors at each side.
A. Kanaan, B. Castilho and collaborators (Kannan et al. In prep.) developed a data reduction procedure based on multi-gaussian fitting that minimize the fiber contamination (the method is briefly described in Kanaan’s web page and SIFS software page: http://www.astro.ufsc.br/~kanaan/ifu/index.html  http://www.lna.br/~sifs/index.html ).

This data reduction method requires the flat field spectra are taken in the beginning of each night for each fiber separately. To minimize the number of exposures we designed a flat field mask to be installed in front of the microlens matrix so the whole flat field map can be done in 5 or 6 images. A retractable mask mechanism will be designed for the FRODOSPEC IFU and will be installed in the input head between the field lens and the microlens matrix. If this solution is approved by JMU the SIFS data reduction software can be provided to JMU and could be easily adapted for FRODOSPEC.
3. Mechanical Layout

The Mechanical Layout follows the two main sub-assemblies division. The Fore-Optics is constituted by a housing and the interfaces with the telescope and the Fibre Cabling Assy. The lenses supports are installed in the housing.

The Fibre Cabling Assy begins with the Input Head, where the fibres are connected. The Input Head can be disconnected from the Fore-Optics when necessary and be stored in an appropriated Storage Support. From the Input Head, the fibres are grouped and inserted in the furcation tubes that are encapsulated in the external metal flexible tube. To avoid stress on the fibres due telescope movements the fibres goes through a strain relief box, and finally the fibres are aligned in a slit to the feed the spectrograph.

In the figures bellow we present a concept of these components and a renderization of the whole assembly based on the actual SIFS design. The cable length is not show in scale. The detailing of the mechanical design for the FRODOSPEC IFU will be developed after the exact optical design and mechanical constrains will be defined in accordance with JMU.

Part of the mechanical structure will be manufactured at LNA workshops and part will be subcontracted from mechanical engineering companies with experience in astronomical instruments. The fibre bundle cable and furcation tubes will be acquired from the same producers as the tested ones acquired for Eucalyptus and SIFS.
Frodospec IFU Mechanical Layout

Input head and its internal detailing
Fibre bundle connection and output slit box
4. Management Plan

4.1. Work Breakdown Structure

The following chart shows the first three WBS levels:

![Work Breakdown Structure Diagram]

4.2. Schedule and Milestones

The project will start with the development of a Conceptual Design where the optical and mechanical concepts will be defined in some detail. The Conceptual Design will be presented to LNA and Liverpool University scientists in the Conceptual Design Review for discussion and improvement. Once approved the Conceptual Design, the Design phase will begin. During this phase, all the project details will be defined as they will be manufactured with proper documentation. A Critical Design Review will be assigned for the project approval and possible improvements. The components will be manufactured and assembled following the design documentation. All manufactured parts and assembled components will be verified for quality control and tested when demanded. After the Manufacturing and Assembly and Testing phases, before shipment, there will be an Acceptance and Testing Meeting to guarantee the IFU attends the requirements. After shipment, commissioning could be performed in loco by LNA Engineers if JMU finds this option adequate.
Considering the proposal is approved by October 7th, 2005, the following milestones were defined:

- Conceptual Design Review – CoDR .................................................. October/31/2005

The CoDR, CDR and ATM will take place at LNA. Liverpool John Moores University Scientists are invited to participate.

### 4.3. Budget

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost - €</th>
</tr>
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<tr>
<td>Conceptual Design and Design</td>
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<tr>
<td>Manufacturing, Assembling and Testing</td>
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</tr>
<tr>
<td>Shipment</td>
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</tr>
<tr>
<td>Comissioning (optional)</td>
<td>3806.68</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>62576.35</strong></td>
</tr>
</tbody>
</table>

### 4.4. Project Team

The project team is the same team which developed the SIFS IFU.

The LNA Optical Scientist Antonio Cesar de Oliveira is Ph.D. in Physics from University of São Paulo – USP/São Carlos, Brazil. He is responsible for LNA Optical Laboratory and the Optical Scientist responsible for SIFS and Eucalyptus IFUs. He was a Post-doc in Instrumentation Applied at Astrophysics at Cerro Tololo Inter-American Observatory - CTIO, Chile and at Anglo-Australian Observatory – AAO, Australia, where he worked in the SPIRAL Spectrograph fibre assembly. He has experience in optical projects systems, optical polishing of optical fibres, optical and laser spectroscopy of solids, interferometric methods for measurements of length, semiconductor lasers, super luminescent diodes and analogic electronics. He also works as a scientific advisor of projects in opto-electronic
industry, visiting Scientist at USP, and Assistant Teaching in Astronomical Observatory at USP.

The LNA Mechanical Engineer Fernando Garcia Santoro is a Ph.D. in Mechanical Engineering from University of São Paulo - USP, Brazil. He is the leader of the LNA mechanical engineering group effort during the development phase of the SIFS Mechanical Project. He is also the head mechanical engineer of an instrument support module with image stabilization system based on Tip-tilt for 1.6m class telescopes. From 2001 to 2004 he was the head mechanical engineer for two Instrument Selector Boxes for SOAR 4m Telescope and from 2000 to 2001 he was the engineer responsible for an Integral Field Unit for 4m Blanco Telescope. He was a Post-doc in instrumentation for large astronomical telescopes at CTIO, Chile, from 1999 to 2003; Ph.D. in unconventional techniques for control system design at USP Metrology Laboratory, Brazil; M.Sc. in helicopter control system design at USP Milling Machine Laboratory, Brazil, where he has worked as a Research Assistant. He also works as a consultant in the mechanical engineering field with high precision components design.

Vanessa Bawden Macanhan is graduated in Mechanical Engineering and M.Sc. in Industrial Engineering, both from Federal University of Itajuba - UNIFEI. In LNA, she has worked in SIFS and STELES Mechanical Projects. She has experience in Project Management and has developed a system for Standard Work Time calculation. She has worked at the project department at Pouso Alegre Unilever plant, Brazil, and in the Logistics Department at AFL, Brazil, where she was the responsible engineer for the plant warehouses. She is a M.Sc. in Economical and Financial Valuation of Assets.

4.5. Project Quality Management

The Project Manager is responsible for ensuring that this project complies with the Statement of Work requirements.

Scheduled and random quality audits are performed during the entire project development to ensure the quality standards are satisfied. Non-conformance observations may arise as a result of project specific or general quality system audits or from general observations. The Project Manager is notified of project quality non-conformance issues and corrective action requests, and provides that the corrective actions are implemented.

As part of the project quality control process, LNA may conduct audits of a subcontractor quality system to ensure that there is compliance with the contract requirements and may perform inspections of the work in progress. LNA always perform inspections of deliverable item procured from a subcontractor to ensure they meet the contract quality requirements. LNA staff may attend testing to be performed by a subcontractor as necessary.
4.6. Project Risk Management

Project Risk Management concerns identifying, analysing, and responding to project risk in order to maximize the results of positive events and minimize the consequences of adverse events.

Based on the head Scientists and Engineers experience and historical events, all risks that may affect the project are identified, mainly its quality, cost and schedule. The risk regarding identification techniques are various, and their choice depends on the area where they are being applied. Some of the most applied techniques are WBS analyses, brainstorming and checklists.

Once identified and documented all the potential risks, they must be analyzed and quantified. Expert judgment is used to quantify quality risks regarding to its probability of occurrence and impact. For cost risk quantification, the techniques usually applied are Expected Monetary Value – EMV and, when necessary, decision trees. Critical Path Method - CPM and Program Evaluation and Review Technique – PERT are the schedule simulation techniques applied for schedule risk quantification.

After identifying and quantifying the risks, the PI, the Project Manager, and the head Scientists and Engineers make decisions in order to pursue the opportunities and respond to threats. When it is possible, threats shall be eliminated, usually by eliminating the causes. If a threat cannot be eliminated, alternative strategies and contingency plans are elaborated. A risk management plan is elaborated if required. Risk response controlling is performed to ensure that the corrective actions have been effective and update the risk management plan if necessary.

5. LNA Capabilities and Facilities

Brazilian astronomy has grown up to 10% a year in the last decade. This growth is in a great extent a consequence of the success of Laboratório Nacional de Astrofísica - LNA, which operates a 1.6-m telescope and two 0.6-m telescopes at Pico dos Dias, Brazópolis, Minas Gerais, Brazil.

In general terms the way Brazilian Astronomy is today has been sketched about 20 years ago. A visionary belief at that time stated that an all-purpose all-community telescope would be the path to the future. In the beginning of the seventies Muniz Barreto from Observatório Nacional and Abrahão de Morais from University of São Paulo proposed the acquisition of a 1.6-m telescope with some instrumentation and the minimum infrastructure needed for operations. A federal agency, FINEP, funded the project.

The 1.6 Telescope saw light for the first time at Observatório do Pico dos Dias - OPD on April 22, 1980. It was officially dedicated by CNPq in February 1981. The new facility became known as Brazilian Astrophysical Observatory and it was administrated as a division of Observatório Nacional until 1984. On March 13, 1985, LNA was created as an
autonomous institute responsible for OPD.

Today LNA is an institute of the Ministry of Science and Technology - MCT, and by far, the most important provider of observational support for the Brazilian astronomical community. LNA supports several post-graduation courses providing the data for M.Sc. and Ph.D. works. LNA's responsibility does not end at this point. The work already done qualifies the Brazilian astronomical community to go ahead with a perspective similar to the one foreseen twenty years ago. Now, the next step is spelled with two words: Gemini and SOAR.

For the best participation on those partnerships, LNA is redirecting efforts to Astronomical Instrumentation. LNA is building a new complex of laboratories, which include more Optics Laboratories, new Mechanics and Electronics Shops, Metrology Laboratory, Integration and Tests Laboratory, among others, to have all the capabilities to build and upgrade great part of its instruments and new ones. This complex will be ready to work by the end of 2005.

6. References


SIFS Homepage. [www.lna.br/~sifs](http://www.lna.br/~sifs).
7. Appendix – SIFS IFU

LNA and USP are building SOAR Integral Field Unit Spectrograph - SIFS, an IFU Bench Spectrograph for SOAR Telescope. The instrument will specialize in the SOAR excellent angular resolution (about 0.15 arcsec, with tip-tilt correction) and medium resolution spectroscopy (R=1000-30000), using an articulated camera and Volume Phase Holographic gratings. SIFS will have a 2-D field coverage of 5x10" using 1300 contiguous spatial elements (lenslets). The core of the optical fibres are of 50µm and the center-to-center separation will be 75µm. The CCD is a 2k x 4k Lincoln Labs (broadband AR coating) giving 3 pixels separation per fibre. Wavelength coverage: 350-1050nm.

Figure 6.1 – SIFS on SOAR
SIFS can be divided in three main sub-assemblies: fore-optics, fibre cable and optical bench. The fore-optics is installed in the optical SOAR Instrument Selector Box - ISB. Connected to the fore-optics there is the Input Box from where the fibres leave. The fibre lays on a rail around the SOAR cage, which rotates 360 degrees. Due to the conduit contractions caused by its rotations, it was designed a Compensation Box to eliminate the contraction effects. In order to avoid traction effects that may damage the fibres, they pass through a Strain Relief Box. Finally, there is an Output Box installed in the entrance of the Optical Bench, where the fibres end.

SIFS optical and mechanical design is completely finished and now its mechanical components are being manufactured. The fibre cable components are being manufactured at LNA and the fore-optics and optical bench components are being manufactured by contractors. The optical fibres are already polished and installed in the conduit.

More information about SIFS can be found at its home page www.lna.br/~sifs.

**Eucalyptus Spectrograph**

To test the use of 50µm core fibres for SIFS and train the team in some techniques necessary to the construction of the SOAR instrument, it was designed and built a prototype spectrograph which is currently operating on the 1.6m Observatório do Pico dos Dias telescope.
This prototype was built by a team from LNA and IAG-USP, based on the projects of the SPIRAL spectrograph, from the Anglo-Australian Observatory. The name *Eucalyptus* was chosen because it is a native Australian tree that adapted very well in Brazil. The first scientific data obtained in February/2001 testify the possibility of using 50µm fibres from the point of view of efficiency and also stability due to torsions and tensions caused by the telescope motion.

More information about Eucalyptus main characteristics, results and pictures can be found at SIFS home page, clicking on “Prototype”.